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PREDICTING INTERNATIONAL CRISES THROUGH STABILITY ANALYSIS,(U)
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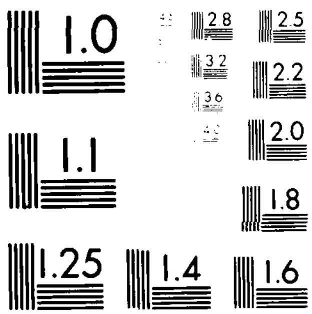

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PREDICTING INTERNATIONAL CRISES THROUGH STABILITY ANALYSIS

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(U) This paper investigates the feasibility of using stability analysis as a medium for predicting international crises. Five international crises that occurred within the last decade were examined using WEIS data on conflictful and cooperative acts. Nine variations on the basic Richardson arms race model theme were used to fit the interactive behavior of the participants of each crisis and to obtain estimates of the relevant parameters. The parameter estimates for the best fitting models were used

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to assess the stability of the interaction pattern in each crisis. In general, (using 95% confidence intervals), these patterns were found to be unstable. Due to data limitations, only one "control" case could be examined; viz., we examined the interaction pattern of a pair of nations during a normal or non-crisis period. While the results are obviously highly tentative, they suggest that non-crisis periods probably do evidence stable reaction patterns. It would appear then that stability analysis may be of some value in forecasting international crises.

ABSTRACT

This paper investigates the feasibility of using stability analysis as a medium for predicting international crises. Five international crises that occurred within the last decade were examined using WEIS data on conflictful and cooperative acts. Nine variations on the basic Richardson arms race model theme were used to fit the interactive behavior of the participants of each crisis and to obtain estimates of the relevant parameters. The parameter estimates for the best fitting models were used to assess the stability of the interaction pattern in each crisis. In general (using 95% confidence intervals), these patterns were found to be unstable. Due to data limitations, only one "control" case could be examined; viz., we examined the interaction pattern of a pair of nations during a normal or non-crisis period. While the results are obviously highly tentative, they suggest that non-crisis periods probably do evidence stable reaction patterns. It would appear then that stability analysis may be of some value in forecasting international crises.

When Richardson proposed his model of an arms race, his interest was not principally in how and why nations accumulate weapons (1960). Richardson's overriding concern was in "deadly quarrels," conflicts in which human lives were lost. Being particularly interested in deadly quarrels involving a large number of deaths, i.e., wars, he had observed that it was often, though not always, the case that wars were preceded by an accumulation of weapons. Richardson felt that it was not so much the existence of the weapons that seemed linked to war but rather the process of accumulation. Suppose, he hypothesized, that arms were accumulated in response to the accumulation by a perceived opponent. Could it be that the resulting pattern of interaction was the clue to the outbreak of war? Perhaps it was the case that the process of ever increasing arms procurements produced an environment of fear such that a small spark would light a major conflagration. This kind of reasoning led Richardson to postulate his arms race model and to examine its "stability" conditions, the specific relationship between the parameters of the model under which the arms race would "run away."

Although an international crisis can be thought of as a more general phenomenon than war, since wars are typically preceded by a crisis but not all crises result in war, Richardson's argument could be equally relevant. Crises, like wars, are typically preceded by nations interacting along a variety of dimensions. If we could capture the dynamics of that interactive process, it might provide a clue that would help us predict the onset of a crisis. Perhaps, like arms races, the interactive pattern,

along whatever dimension, say expressions of anger and hostility, is continually escalating. Then, like two quarreling people, the escalation may lead to a crisis, a peak at which the two either decide to "cool off" or move to the next level of overt violence. It was this analogy to Richardson's efforts that led to the research to be presented here. Specifically, it led us to pose the question: are interaction patterns prior to a crisis typically unstable?

DATA CONSIDERATIONS

To provide an adequate answer to this question requires a series of prior decisions. First, it is necessary to select the appropriate dimension or variable along which to observe the interaction patterns. If our focus is on crisis, then variables like trade, mail exchanges, migration, are probably not appropriate. Although other variables may be equally relevant, it seemed best to begin the examination with overt acts that reflect some degree of hostility. Thus some type of events data seemed most appropriate and because of its classification of events in terms of different forms of hostile behavior, and its extensive coverage both in terms of nations and time (1966-77), the WEIS data set was chosen. The WEIS data consist of events recorded by nation and day, and classified on the basis of different forms of conflictual and cooperative behavior. Whenever possible the events are further coded with respect to both initiator and target. This latter fact was particularly useful for our purposes. Since we planned to focus on crises involving specific pairs of countries, it was important to know to whom a hostile act was directed. However, because of the limited amount of data, we used not only those conflict acts that were initiated by one crisis participant and targeted

at the other participant, but also all non-targeted behaviors when initiated by either participant. We excluded those events initiated by one of the participants but directed elsewhere in the system and those events that were initiated by some other state and received by a crisis participant. While subsequent analyses might well wish to incorporate these data, it appeared reasonable to begin with a narrowed set of events. Although our analysis began with a focus on conflict behavior, as will be seen below, we subsequently incorporated cooperative acts.

Having selected a relevant data set, the next issue was the appropriate measurement procedure. The simplest procedure is, of course, a straight frequency count, viz., the number of conflict acts per some unit of time. Such a procedure, however, implicitly assumes that each event contributes equally to the underlying process being examined. Hence, it seemed important to consider alternate assumptions. First, a simple weighting procedure was used in which the events were assigned a value of 1, 2, 3, etc. depending on the intensity value of the event. This was determined by using the scale implicit in the ranking of the events in the WEIS code book. Beginning with "reject," "accuse," "protest," etc., these were assigned values of 1, 2, 3, etc. on the conflict intensity scale. The second procedure scaled the events by transforming them into z scores, a technique that has been successful in the work that others have done using the WEIS data (Andriole and Young, 1977). A mean and standard deviation were computed for the frequency of the conflict events over the time intervals chosen. The z score for a given interval was then found by subtracting the total frequency of conflict acts for that period from the mean frequency and dividing by the standard deviation. The

third and final approach to the scaling issue involved expressing the frequency of conflict acts in a given interval as a proportion of the total number of events, cooperative and conflictual, that took place during that time period. This is comparable, but not identical, to the Tension measure used by Andriole and Young (1977).

Ideally, of course, it would have been desirable to use the day as the time interval, as this would provide a large number of data points for the purposes of estimation. Unfortunately, however, the data are too sparse to permit this and such an approach simply produces a large number of zero entries. Hence, we decided to work with time intervals of 10 days. This aggregation of the data seemed to minimize the number of zero entries without unduly decreasing the number of data points for estimation purposes.

Clearly the next problem was the selection of crises. To ensure a comparable time frame, we decided to consider only crises that had occurred within the last decade. In this regard we were greatly aided by the work of Designs and Decisions, Inc., Memo #14 which has produced a project memo listing 27 crises. While the definition of a crisis is more intuitive than explicit in this list, it provides a reasonable starting point for analysis. For the purposes of an initial analysis, we selected five crises from this list. Although it would have been desirable to make the selection on certain substantive grounds, the sparseness of the data compelled us to select crises for which an adequate number of events had occurred to permit reasonable statistical estimation. Thus the six-month period prior to each of the 22 crises was examined and the five with the greatest number of prior events were selected. While such a procedure may appear atheoretical, it is, nevertheless,

the case that the five crises so selected do reflect some of the more interesting ones on the list:

1. USSR vs. People's Republic of China; December, 1966: period of increasing hostility beginning in 1956 with the Soviet's destalinization, culminates in December of 1966 with the Communist Party of the Soviet Union using Mao's name in condemning China's policies. A series of incidents follow.
2. USSR vs. Czechoslovakia; August, 1968: internal liberalization of Czechoslovakia leads to USSR military intervention in August of 1968.
3. USSR vs. USA; September, 1970: the Jordanian civil war which grew out of clashes between Jordanian based Palestinians and Israelis brings the super powers into a confrontation when the US moves warships into nearby waters on the grounds of a possible need to protect American lives.
4. India vs. Pakistan; November, 1971: the beginning of the third India-Pakistan war which resulted from East Pakistan (now Bangladesh)'s declaration of independence from West Pakistan.
5. USSR vs. USA; October, 1973: on October 25 the United States placed its military forces on world wide precautionary alert on the grounds that the Soviets appeared to be planning to introduce forces in the Middle East.

As can be seen from these brief descriptions, these five crises cover different parts of the globe and a variety of different participants. In addition, they include some of the major crises of the past decade. The only obviously missing cases are those involving the Arabs and Israelis, pairs for which there was an inadequate amount of data in the WEIS set.

For each of the five crises then, we aggregated the data by ten-day time periods for the six months prior to the month in which the crisis began. This produced 18 data points per crisis. For each of these data points, however, it must be recalled that we have four measurement procedures: frequency, scaled, z score and proportion. Thus for each crisis we have in effect four different sets of 18 data points.

THE MODELS

We come finally to the models. All of the models examined here here are simple variations on the Richardson arms race model, but formulated in difference rather than differential equations. Our first two models can be seen as degenerate forms of the Richardson model and were principally included to see whether the more complex Richardson model would afford an appreciably better fit than these simpler versions. Thus we proposed:

Model 1: $$\Delta x = a_{11}x(t-1) + g$$
$$\Delta y = a_{22}y(t-1) + h$$

Model 2: $$\Delta x = a_{12}y(t-1) + g$$
$$\Delta y = a_{21}x(t-1) + h$$

Model 3: $$\Delta x = a_{11}x(t-1) + a_{12}y(t-1) + g$$
$$\Delta y = a_{21}x(t-1) + a_{22}y(t-1) + h$$

where x and y: are the amount of conflictful or hostile actions emitted by one participant towards the other (or towards an unspecified target)

$$\Delta x = x(t) - x(t-1)$$
$$\Delta y = y(t) - y(t-1)$$

Although Richardson assumed the a_{ij} coefficients to be positive and subtracted $a_{12}y$ and $a_{21}x$, it seems wiser not to make such assumptions and to treat the more general case as given in Model 3. It can readily be seen that Model 1 can be obtained from Model 3 by letting $a_{12} = 0 = a_{21}$, while Model 2 can be acquired by letting $a_{11} = 0 = a_{22}$.

Model 1 suggests that a nation's increase or decrease in emission of hostility is purely a function of what it did previously while Model 2 proposes instead that it is a function of the hostility emitted by the opponent. Model 3 incorporates both Models 1 and 2 and argues that it is the combination of what a nation did previously together with the hostility received that produces the increase or decrease in hostility.

Models 1, 2 and 3 were proposed to account for the conflictual or hostile interactions of a pair of nations. However, it is not unlikely that a pair of nations may be simultaneously emitting both hostile and cooperative acts towards one another. Although our proportional measurement procedure could capture one facet of this dual form of interaction, we were concerned that Models 1, 2 or 3 might mask an important and interesting dynamic by not explicitly incorporating cooperative acts. Thus we proposed three additional models incorporating the variable, cooperation:

Model 4:
$$\Delta x = a_{11}x(t-1) + a_{12}y(t-1) + u(t-1) + g$$
$$\Delta y = a_{21}x(t-1) + a_{22}y(t-1) + v(t-1) + h$$

Model 5:
$$\Delta x = a_{11}x(t-1) + a_{12}y(t-1) + v(t-1) + g$$
$$\Delta y = a_{21}x(t-1) + a_{22}y(t-1) + u(t-1) + h$$

Model 6:
$$\Delta x = a_{11}x(t-1) + a_{12}y(t-1) + u(t-1) + v(t-1) + g$$
$$\Delta y = a_{21}x(t-1) + a_{22}y(t-1) + u(t-1) + v(t-1) + h$$

where u: cooperation directed by x to y or sent by x to an unspecified target.

v: cooperation directed by y to x or sent by y to an unspecified target.

As should be clear from the statement of the equations in Models 4, 5 and 6, the variables u and v are being treated as exogenous inputs to the systems described by the Richardson equation. The principal difference between these three models lies in the different assumptions as to whose cooperative acts affect whom. In Model 4 the presumption is that one's own cooperative acts, being a measure of the residue of good will felt toward the opponent, have some impact on one's own emission of hostility. In Model 5, however, the assumption is that it is the cooperative acts of the opponent that have an impact on one's emission of hostility. Finally, Model 6 incorporates the assumptions of both Models 4 and 5.

Since we have only implicitly discussed the procedure for measuring the variable "cooperation," perhaps we should indicate at this point how this was done. While all four techniques for measuring hostility could obviously be used to measure cooperation, viz., frequency, scaled, z scores and proportions, the use of proportions in the above three models seemed somewhat redundant. If hostility was measured as the number of hostile acts divided by the number of hostile plus cooperative acts, then obviously the comparable measure for cooperation would simply be 1 minus this value. Thus it was decided not to use the proportional measure in testing Models 4, 5 and 6. Thus these three models are only tested with frequency, scaled and z score measures for hostility and cooperation. The scaled measure was obtained by assigning "propose," "request," "agree," etc. values of 1, 2, 3, etc. on a cooperation scale.

Thus indirectly through the use of the proportion measure in testing Models 1, 2 and 3 and more directly in the addition of the cooperation variable in Models 4, 5 and 6, the attempt was made to capture the impact of cooperation on hostile interactions. But there appeared to be yet another possibly more plausible way to incorporate cooperation in the models. Instead of thinking of cooperation as a separate input variable, as in Models 4, 5 and 6, suppose we thought of two nations interacting in terms of what might be called "net hostility." Suppose we considered the amount of hostility minus the amount of cooperation as a measure of "residue" or "net hostility." Seen from this perspective, we would have a new variable (x-u) or (y-v) that would combine hostility and cooperation. This reasoning led us to propose three final models, models which are simply restatements of Models 1, 2 and 3 using the newly defined "net hostility" variable:

Model 7:
$$\Delta(x-u) = a_{11}[x(t-1) - u(t-1)] + g$$
$$\Delta(y-v) = a_{22}[y(t-1) - v(t-1)] + h$$

Model 8:
$$\Delta(x-u) = a_{12}[y(t-1) - v(t-1)] + g$$
$$\Delta(y-v) = a_{21}[x(t-1) - u(t-1)] + h$$

Model 9:
$$\Delta(x-u) = a_{11}[x(t-1) - u(t-1)] + a_{12}[y(t-1) - v(t-1)] + g$$
$$\Delta(y-v) = a_{21}[x(t-1) - u(t-1)] + a_{22}[y(t-1) - v(t-1)] + h$$

where x, u, y and v are defined as above. Due to time and resource constraints, Models 7, 8 and 9 were tested only with the frequency and scaled measures of hostility and cooperation.

Because of the variety of models and different measurement procedures used on the variables, Table 1 is given as a general summary of what tests

were made on which models. It should be noted that those models involving both hostility and cooperation used the same measurement procedure for both variables, e.g., if hostility was measured using z scores, cooperation would be similarly measured.

THE ANALYSIS

It will be recalled that our basic hypothesis is that hostile interaction patterns should evidence instability before crisis periods, i.e., exchanges of hostility, however measured, should be continually increasing between crisis participants. There are two principal stages in testing this general thesis. First, we must find the model that provides the best possible fit to the hostile exchanges of a particular crisis; and second, having found the best model, we must use the parameter estimates obtained from that model to test for the stability of the exchange pattern. The details of these two stages are outlined below.

Each crisis contains two major participants and thus each model contains two equations. From a theoretical perspective, these equations represent a pair of coupled difference equations. One might suspect that the most desirable method of estimating such a model would be the use of simultaneous equation procedures where information from one equation effects the estimation of the other. However, from a statistical perspective, these equations are not simultaneous since neither contains as a predetermined variable the endogenous variable from the other equation. Therefore, we have used the appropriate single equation methods. An implication of this procedure, however, is that in a given crisis one might and (and indeed does) find that one model best fits one crisis participant while another model best fits the other participant.

TABLE 1

MEASUREMENT PROCEDURES

MODELS		FREQUENCY	SCALED	Z SCORED	PROPORTION
(1)	$\Delta x = a_{11}x(t-1) + g$ $\Delta y = a_{22}y(t-1) + h$				
(2)	$\Delta x = a_{12}y(t-1) + g$ $\Delta y = a_{21}x(t-1) + h$				
(3)	$\Delta x = a_{11}x(t-1) + a_{12}y(t-1) + g$ $\Delta y = a_{21}x(t-1) + a_{22}y(t-1) + h$				
(4)	$\Delta x = a_{11}x(t-1) + a_{12}y(t-1) + u(t-1) + g$ $\Delta y = a_{21}x(t-1) + a_{22}y(t-1) + v(t-1) + h$				
(5)	$\Delta x = a_{11}x(t-1) + a_{12}y(t-1) + v(t-1) + g$ $\Delta y = a_{21}x(t-1) + a_{22}y(t-1) + u(t-1) + h$				
(6)	$\Delta x = a_{11}x(t-1) + a_{12}y(t-1) + u(t-1) + v(t-1) + g$ $\Delta y = a_{21}x(t-1) + a_{22}y(t-1) + u(t-1) + v(t-1) + h$				
(7)	$\Delta(x-u) = a_{11}[x(t-1) - u(t-1)] + g$ $\Delta(y-v) = a_{22}[y(t-1) - v(t-1)] + h$				
(8)	$\Delta(x-u) = a_{12}[y(t-1) - v(t-1)] + g$ $\Delta(y-v) = a_{21}[x(t-1) - u(t-1)] + h$				
(9)	$\Delta(x-u) = a_{11}[x(t-1) - u(t-1)] + a_{12}[y(t-1) - v(t-1)] + g$ $\Delta(y-v) = a_{21}[x(t-1) - u(t-1)] + a_{22}[y(t-1) - v(t-1)] + h$				

NOTE: Shaded squares indicate those tests which were not made.

An important characteristic of our estimation procedure is that we treat the Δx or Δy as a variable distinct from the variables on the right-hand side of the equation. This has the effect of reducing each equation to either bivariate or multivariate regression. For example, consider Model 3:

$$x(t) - x(t-1) = a_{11}x(t-1) + a_{12}y(t-1) + g$$

$$y(t) - y(t-1) = a_{21}x(t-1) + a_{22}y(t-1) + h$$

These equations could be rewritten as

$$x(t) = (a_{11} + 1)x(t-1) + a_{12}y(t-1) + g$$

$$y(t) = a_{21}x(t-1) + (a_{22} + 1)y(t-1) + h$$

But by so rewriting the equations, we have created a lagged endogenous variable which causes some statistical difficulty. By treating the dependent variable as a distinct variable from the independent variables, as is implied in the original form of Model 3, we avoid these problems. In effect then, our analysis is a regression of the form

$$z_1(t) = a_{11}x(t-1) + a_{12}y(t-1) + g$$

$$z_2(t) = a_{21}x(t-1) + a_{22}y(t-1) + h$$

Although this form of Model 3 avoids the problem of a lagged endogenous variable, since we are estimating through time, it is still necessary to test for autocorrelated error and make the necessary adjustments when it occurs. Thus all models were tested with the Durbin-Watson statistic and necessary adjustments made when required. Finally,

it should be obvious that our models are not always comparable in terms of the number of independent variables. Hence, to allow for comparisons across models, adjusted R^2 were calculated. All results reported here are for adjusted R^2s following changes required by the Durbin-Watson test.

The above analysis permits us to choose that model and that measurement technique that provides the best fit to a particular pair of participants prior to a given crisis. Thus, having found the best fitting model, the regression provides estimates for the parameters of the model. It is these estimates that play a critical role in the second stage of our analysis. To illustrate how the stability of a model is determined, consider Model 3:

$$\Delta x(t) = a_{11}x(t-1) + a_{12}y(t-1) + g$$

$$\Delta y(t) = a_{21}x(t-1) + a_{22}y(t-1) + h$$

which as shown above can be rewritten as*

$$x(t) = (a_{11} + 1)x(t-1) + a_{12}y(t-1) + g$$

$$y(t) = a_{21}x(t-1) + (a_{22} + 1)y(t-1) + h$$

and even more compactly written in matrix notation as

$$z(t) = Az(t-1) + v$$

where

$$z(t) \equiv \begin{bmatrix} x(t) \\ y(t) \end{bmatrix}, \quad v \equiv \begin{bmatrix} g \\ h \end{bmatrix}, \quad A \equiv \begin{bmatrix} a_{11} + 1 & a_{12} \\ a_{21} & a_{22} + 1 \end{bmatrix}$$

*Note that the stability analysis occurs after the estimation procedures are completed and, therefore, is not relevant to the statistical issues raised above, including those concerning lagged endogenous variables.

The characteristic equation for the matrix A is defined as

$$[(a_{11} + 1) - \lambda][(a_{22} + 1) - \lambda] - a_{12}a_{21} = 0$$

which can be written as

$$\lambda^2 - [a_{11} + a_{22} + 2]\,\lambda + [a_{11}a_{22} + a_{11} + a_{22} + 1 - a_{12}a_{21}] = 0$$

If we define

$$c_1 \equiv a_{11} + a_{22} + 2$$

$$c_2 \equiv a_{11}a_{22} - a_{12}a_{21} + a_{11} + a_{22} + 1$$

we can write the characteristic equation as

$$\lambda^2 - c_1\lambda + c_2 = 0$$

for which it is easy to show that

$$\lambda_1, \lambda_2 = \frac{1}{2}\,[c_1 \pm\sqrt{c_1^{\,2} - 4c_2}]$$

If when these calculations are carried out, it is found that $\lambda_i > 1$ <u>or</u> $\lambda_i < -1$, $i = 1, 2$ then the system is <u>unstable</u>. In short, once we obtain estimates for the parameters of the best fitting model, we form the characteristic equation as described above and solve for the λ's. If the one of the λ's fall outside the ± 1 range, the system is <u>unstable</u>.

It is important to note that stability as discussed above is dichotomous, a system is considered to be either stable or unstable. However, such an interpretation may be unreasonable given the fact that λ can in effect assume <u>any value</u>. Thus, for example, a system in which one λ is .8 could

reasonably be considered close to unstable even though .8, strictly speaking, makes the system stable. We will want to return to this issue when we consider the results.

One final point. As should be obvious, the stability or instability of a system depends entirely on the A matrix, i.e., on the parameters that are estimated from the regression analysis. However, estimates are only estimates and obviously contain some error. It, therefore, seemed reasonable to not only test the stability of a system for the original estimates obtained, but to consider further the 95% confidence interval around those estimates. Consequently, we have in effect <u>three</u> stability analyses per model, one for the original estimates, and one each for those values that form the upper and lower bounds for the 95% confidence interval. How does one interpret such results? A theorem states that if a system is unstable for a given set of parameter estimates, i.e., a particular A matrix, then that system will be unstable in a region about those values (Krasovskii, 1963, pg. 83; Zubov, 1964, pg. 160). Suppose we obtained a set of parameter estimates and considered the 95% confidence interval about those values. Suppose further that the upper bound of the confidence interval estimates produced eigenvalues that lay outside the ±1 range indicating that for these parameter values the system was unstable. We can conclude from this <u>not only that the system will be unstable if those are the true parameter estimates, but further, that the system is also unstable for estimates of the parameters in an interval around each of those estimates</u>.

<u>RESULTS</u>

Tables 2, 3 and 4 report the adjusted R^2 values for each participant

in each crisis in terms of the various measurement procedures and for each model. Models 1 and 7 are combined in Table 2 to offer a comparison between the simple hostility data and the "net hostility" data (hostility - cooperation). For similar reasons, Models 2 and 8 are combined in Table 3. Table 4 contrasts the various versions of the basic Richardson model.

There are two questions that need to be examined in these tables: (1) can we detect any appreciable difference between the fits of the different models; and (2) does it make any difference across models whether we use one measurement procedure or another? There are at least two ways we might answer either of these questions. First, we might ask about which model best fits each crisis and which measurement procedure gives the best fit for each crisis. We will, in effect, turn to this approach when considering the stability analyses. There is, however, a second approach worth consideration. Suppose a decision maker had to choose between these models and scaling procedures, over all the crises, which model and measurement technique gives the best results? If we look down the columns of either Tables 2, 3 or 4, it is clear that there is no obvious answer to this question, for some crises some models and some measurement techniques do better than others, but there is no uniform pattern. On the other hand, one senses that some models and measurement procedures generally do better than others, even though there are deviate cases. For example, it would seem obvious that Models 2 and 8 are overall exceedingly poor regardless of what measurement technique is used.

To aid in this assessment, we have calculated the mean adjusted R^2, $\bar{x}_r$ and standard deviation σ_r across crises for each model and each measurement technique, and these are given in each table on the bottom lines. The mean adjusted R^2 indicates, on the average, how well the model fits over

TABLE 2

A COMPARISON OF ADJUSTED R^2 FOR MODELS 1 AND 7

CRISIS	YEAR	COUNTRY	M 1 CO	M 1 CP	M 1 CS	M 1 CZ	M 7 CO	M 7 CS
USR-CHN	1966	USR (x)	.310*	.415**	.343**	.310*	.403**	.468**
		CHN (y)	.446*	.670**	.479**	.446**	.521**	.614**
USR-CZE	1968	USR (x)	-.056	.205*	-.057	-.056	.523**	.511**
		CZE (y)	.084	.383**	.222**	.084	.550**	.464**
USR-USA	1970	USR (x)	.814**	.425**	.781**	.814**	.635**	.679**
		USA (y)	.619**	.616**	.662**	.619**	.710**	.712**
IND-PAK	1971	IND (x)	.780**	.697**	.720**	.780**	.608**	.506**
		PAK (y)	.386**	.416**	.437**	.386**	.472**	.556**
USR-USA	1973	USR (x)	.061	.545**	.292**	.061	.220**	.226**
		USA (y)	.371**	.430**	.420**	-.006	.491**	.522**
		$\bar{x}_r$	.3927	.4802	.4413	.3562	.5133	.5258
		σ_r	.2804	.1509	.2289	.3061	.1351	.1352

NOTE:

CO: Frequency
CP: Conflict Proportional to Total
CS: Scaled
CZ: Z Scores

Significance Level

**(.01)
*(.05)

TABLE 3

A COMPARISON OF ADJUSTED R^2 FOR MODELS 2 AND 8

			M 2				M 8	
CRISIS	YEAR	COUNTRY	CO	CP	CS	CZ	CO	CS
USR-CHN	1966	USR (x)	.136	.172	.031	.136	-.030	-.066
		CHN (y)	.125	.217*	.167	.125	.042	.038
USR-CZE	1968	USR (x)	-.040	.005	-.056	-.040	.150	-.009
		CZE (y)	-.060	-.058	.067	-.062	-.062	-.019
USR-USA	1970	USR (x)	.048	.022	.240*	.048	.120	.261*
		USA (y)	.093	-.003	.204*	.093	-.008	.269*
IND-PAK	1971	IND (x)	.178*	-.062	.240*	.178*	-.064	-.050
		PAK (y)	.700**	-.016	.574**	.700**	.204*	-.034
SR-USA	1973	USR (x)	.113	.077	.022	.113	.058	.005
		USA (y)	-.013	.040	-.062	-.013	-.065	-.056
		$\bar{x}_r$	.1506	.0672	.1663	.1508	.0803	.0807
		σ_r	.1995	.0728	.1669	.1994	.0599	.0991

NOTE:

CO: Frequency
CP: Conflict Proportional to Total
CS: Scaled
CZ: Z Scores

Significance Level

**(.01)
*(.05)

TABLE 4

A COMPARISON OF ADJUSTED R^2 FOR MODELS 3, 4, 5, 6 AND 9

CRISIS YEAR COUNTRY	M 3 CO	M 3 CP	M 3 CS	M 3 CZ	M 4 CO	M 4 CZ	M 4 CS	M 5 CO	M 5 CZ	M 5 CS	M 6 CO	M 6 CZ	M 6 CS	M 9 CO	M 9 CS
USR-CHN 1966 USR(x)	.260*	.385*	.299*	.260*	.211	.211	.259	.222	.222	.363*	.159	.159	.318	.425*	.482**
CHN(y)	.429**	.648**	.449**	.429**	.385*	.385*	.429*	.390*	.390*	.417*	.340*	.340	.396*	.506**	.598**
USR-CZE 1968 USR(x)	-.026	.420**	-.129	-.026	-.094	-.094	-.076	-.064	-.064	-.209	-.110	-.110	-.079	.692**	.683**
CZE(y)	.230	.373*	.474**	.230	.175	.175	.459*	.174	.174	.446*	.107	.107	.416*	.520**	.427**
USR-USA 1970 USR(x)	.808**	.419**	.769**	.808**	.795**	.795**	.756**	.802**	.802**	.754**	.785**	.785**	.737**	.624**	.657**
USA(y)	.593**	.601**	.640**	.593**	.563**	.563**	.627**	.569**	.569**	.612**	.533**	.533**	.597**	.701**	.692**
IND-PAK 1971 IND(x)	.900**	.695**	.787**	.900**	.751**	.791**	.601**	.693**	.681**	.531**	.737**	.840*	.568**	.729**	.549**
PAK(y)	.679**	.679**	.555**	.668**	.916**	.913**	.785**	.909**	.894**	.796**	.915**	.907**	.783**	.512**	.526**
USR-USA 1973 USR(x)	.409**	.409**	.362*	.409**	.626**	.444*	.404*	.401*	.364*	.354*	.603**	.429*	.395*	.190	.199
USA(y)	.328*	.328*	.390*	.328*	.381*	.302	.391*	.294*	.443*	.350*	.335	.400*	.349	.539**	.561**
$\bar{x}_r$	.4662	.4957	.4854	.4651	.4897	.4673	.4787	.4518	.4603	.4832	.4624	.4610	.4638	.5438	.5374
σ_r	.2753	.1423	.2076	.2744	.2835	.2877	.2197	.2819	.2740	.1885	.2949	.3003	.2106	.1597	.1467

NOTE:

CO: Frequency
CP: Conflict Proportional to Total
CS: Scaled
CZ: Z Scores

Significance Level

**(.01)
*(.05)

all crises and participants; the standard deviation indicates how deviant the fits were across cases. These values, together with the median adjusted R^2, as a comparison to the mean, are repeated in Tables 5 and 6 for greater visual clarity. It is clear from Table 5 that Model 2 and its "net hostility" counterpart, Model 8, are hopeless regardless of which measurement technique is used. Both the mean and median adjusted R^2 values for these models are extremely small. It is also clear from Table 5 that Model 1 provides reasonably good fits, the best fit probably occurring with the proportion measure; the mean adjusted R^2 is the best of all the measurement procedures for this model and the standard deviation is the lowest. However, Table 5 further indicates that Model 1 can be improved by consideration of its "net hostility" version, Model 7. When using the scaled procedure, the adjusted mean R^2 is the highest in the table and its standard deviation is among the lowest.

To what extent can we improve upon the fit for Model 7? A glance down the columns of Table 6 for the remaining five models shows that only when we get to Model 9 do we reach a higher mean R^2. While the standard deviation is somewhat greater for the CO version of Model 9 than was true for the CS version of Model 7, it is, nevertheless, the case that the CO version of Model 9 provides an overall better fit. Model 9, it will be recalled, is the net hostility version of the basic Richardson model. Thus if a decision maker were faced with having to choose among these models for the purposes of estimating parameters, he would do best by using Model 9.

It is interesting to note the relationship between Model 7 and Model 9. Both, of course, are formulated in terms of "net hostility" so it is clear that better fits are obtained when we subtract cooperative

TABLE 5

A COMPARISON OF ADJUSTED R^2 VALUES FOR MODELS 1, 7, 2, 8

		MEAN R^2	MEDIAN R^2	STANDARD DEVIATION
M 1				
	CO	.3927	.379	.2804
	CP	.4802	.427	.1509
	CS	.4413	.427	.2289
	CZ	.3562	.348	.3061
M 7				
	CO	.5133	.522	.1351
	CS	.5258	.518	.1352
M 2				
	CO	.1506	.103	.1995
	CP	.0672	.051	.0728
	CS	.1663	.117	.1669
	CZ	.1508	.103	.1994
M 8				
	CO	.0803	.064	.0599
	CS	.0807	.053	.0991

TABLE 6

A COMPARISON OF ADJUSTED R^2 VALUES FOR MODELS 3, 4, 5, 6, 9

		MEAN R^2	MEDIAN R^2	STANDARD DEVIATION
M 3				
	CO	.4662	.369	.2753
	CP	.4957	.420	.1423
	CS	.4854	.461	.2076
	CZ	.4651	.419	.2744
M 4				
	CO	.4897	.454	.2835
	CZ	.4673	.414	.2877
	CS	.4787	.444	.2197
M 5				
	CO	.4518	.396	.2819
	CZ	.4603	.416	.2740
	CS	.4832	.428	.1885
M 6				
	CO	.4624	.431	.2949
	CZ	.4610	.414	.3003
	CS	.4638	.406	.2106
M 9				
	CO	.5438	.529	.1597
	CS	.5374	.578	.1467

acts from hostile acts. The difference between Models 7 and 9 lies in the fact that Model 9 contains the interactive term. While Model 7 postulates that the changes in a nation's net hostility are a simple function of the net hostility earlier, Model 9 further considers the net hostility that is being emitted by the opponent. Although Model 9 provides an overall better fit than Model 7, it is clear that the difference between the two fits is small. This clearly suggests that changes in net hostility are largely a function of what the nation did in the previous time period. In short, the activities of the opponent are of less importance than one's own previous actions.

Can we similarly argue that one measurement technique is superior across all models and crises? Here the results are less obvious. However, a comparison of Models 1 and 3 shows that the z score procedure is definitely inferior to the other three procedures (we omit Model 2 because of its extremely poor fits). But having eliminated the z scoring approach, it is not entirely clear which of the remaining three is superior. It seems to depend on the model as to which measurement is best.

Having found the best fitting model, Model 9, we turn next to the stability analysis. Using the parameters estimated for Model 9 for each crisis participant, we can assess the stability of the interactions as described in the previous section. As noted before, we will wish to do this for the actual estimates and for those values generated by considering the 95% confidence interval around those estimates, producing in effect three stability analyses for each crisis. Although our principal concern is with Model 9, since Model 7 provided nearly as good fits, it would seem important to similarly consider Model 7's stability properties. One additional set of analyses would also seem in order.

A perusal of Table 4 shows that while Model 9 provides the best fit over all crises, it is not the case that it always provides the best fit for each and every crisis. For example, the crisis between the USSR and USA in 1970 finds a considerably better fit under Models 1 or 3. This would suggest that we should consider the best fitting model for each crisis to determine whether different stability results are obtained than when using the overall best fitting model. We could push this analysis yet one step further and find for each participant the best fitting equation and then combine per crisis the best fitting equations. Such a procedure, however, would create asymmetric models, making the stability analysis more complex and thus is reserved to a subsequent series of tests.

Table 7 reports the stability analysis for Model 9 using the simple frequency measure for both hostility and cooperation. The first two columns of this table give the eigenvalues based on the actual estimates obtained when Model 9 was fitted to each nation's "net hostility" behavior. It will be recalled that the system is unstable if one of the eigenvalues exceeds +1 or is less than -1. A perusal of the first two columns of Table 7 shows that when the original estimates are used, all interaction periods prior to the crisis are assessed as stable. Columns 4 through 7 report the eigenvalues for the 95% confidence interval around the original estimates. When we consider the 95% confidence estimates, we find that three of the crisis periods are clearly unstable, i.e., at least one of the four eigenvalues for these three crises exceeds +1. As discussed earlier, this indicates that the system will be unstable not only for these particular values of the parameters but for other values of the parameters within a region about these estimates. In short, using 95% confidence estimates, it can be said that there exist probable parameter

TABLE 7

STABILITY ANALYSIS OF MODEL 9 USING CO MEASUREMENT

CRISIS	YEAR	ORIGINAL ESTIMATES λ_1	ORIGINAL ESTIMATES λ_2	STABLE or UNSTABLE	95% CONFIDENCE INTERVAL ESTIMATES λ_1	λ_2	λ_1	λ_2	STABLE or UNSTABLE
USR-CHN	1966:	-.0836	-.2744	S	-.72	-.48	1.48	-.98	U
USR-CZE	1968:	-.2442	-.4198	S	-.98	-.84	1.19	-.67	U
USR-USA	1970:	-.2076	-.1604	S	-.44	-.89	.50	.10	?
IND-PAK	1971:	-.1914	.0914	S	-.60	-.44	.66	.17	?
USR-USA	1973:	.2391	.1499	S	-.14	-.54	1.19	.27	U

values for these crises, such that the system will be unstable.

What about the question marks in the last column of Table 7? As described earlier, a system is stable so long as it remains within the +1 to -1 region. However, since the eigenvalues can take on any value within this interval, it can be argued that one ought to discriminate between values around 0, which are clearly very stable, and values that begin to approach the region of instability. The difficulty, of course, is in defining the cutoff point. An intuitively reasonable argument can be made for saying that values between +.5 and -.5 are <u>very</u> stable while those that lie between +.5 and +1 or -.5 and -1 indicate that the system could be unstable. If this argument is accepted, then the two remaining crises listed in Table 7 can also be deemed unstable, or at least approaching instability. It is for this reason that these two crises are labeled with question marks.

What happens when we consider the next best fitting model, Model 7? Table 8 gives the stability results for this analysis. Once again, we find that using the original estimates all crises produce stable interaction patterns. However, when we move to the 95% confidence intervals, the results are not as clear cut as in the case of Model 9. None of the crises are clearly unstable. However, using the .5 cutoff point as just discussed, all five crises could be considered to fall in the danger region of being more unstable than stable.

We turn then to a consideration of the stability analyses of the best fitting models for each crises. These results are reported in Table 9. The first column of Table 9 reports the average adjusted R^2 over the two nations in the crises and the standard deviation as some indication of how different the two fits are. For comparison purposes, columns 3 and 4

TABLE 8

STABILITY ANALYSIS OF MODEL 7 USING CS MEASUREMENT

		ORIGINAL ESTIMATES		STABLE or UNSTABLE	95% CONFIDENCE INTERVAL ESTIMATES				STABLE or UNSTABLE
CRISIS	YEAR	λ_1	λ_2		λ_1	λ_2	λ_1	λ_2	
USR-CHN	1966:	-.1288	-.1603	S	-.67	-.70	.42	.38	?
USR-CZE	1968:	-.1223	-.2067	S	-.69	-.85	.46	.43	?
USR-USA	1970:	-.1740	-.2160	S	-.56	-.65	.22	.21	?
IND-PAK	1971:	-.0876	-.0904	S	-.61	-.61	.44	.43	?
USR-USA	1973	.2686	.1674	S	-.22	-.33	.76	.66	?

TABLE 9

STABILITY ANALYSIS FOR BEST FITTING MODEL FOR EACH CRISIS

CRISIS YEAR	BEST FIT MODEL		M 9 CO FIT		ORIGINAL ESTIMATES		STABLE or UNSTABLE	95% CONFIDENCE INTERVAL ESTIMATES				STABLE or UNSTABLE
	MEAN R^2	σ_r	MEAN R^2	σ_r	λ_1	λ_2		λ_1	λ_2	λ_1	λ_2	
USR-CHN 1966 Best Fit Model: M 1 CP	.543	.180	.466	.057	-.1086	-.2085	S	-.66	-.73	.44	.31	?
USR-CZE 1968 Best Fit Model: M 9 CO	.606	.122	.606	.122	-.2442	-.4198	S	-.98	-.84	1.19	-.67	U
USR-USA 1970 Best Fit Model: M 1 CS	.722	.084	.663	.054	-.0795	-.0805	S	-.42	-.43	.27	.27	S
IND-PAK 1971 Best Fit Model: M 4 CZ	.852	.086	.621	.153	.2718	-.1378	S	.004	-.78	.853	.198	?
USR-USA 1973 Best Fit Model: M 4 CO	.504	.173	.365	.247	-.0073	.0683	S	-1.31	-.78	2.28	-.07	U

report the mean adjusted R^2 and standard deviation for the same two nations for the best overall fitting Model 9 when using the frequency data. As can be seen by comparison of the first two columns with columns 3 and 4, Model 9 provides the best fit only for the USSR-Czechoslovakia 1968 crisis; in all other instances considerably better fits are obtained with other models, the most striking difference perhaps occurring for the Indian-Pakistan 1971 crisis. However, although better fits are obtained when using other models, it appears that, with one exception, the stability analysis does not drastically change. Comparing Table 7 for the overall best fitting Model 9 with the results found in Table 9 for the individual crisis best fitting models, we see that with the exception of the USSR-USA, 1970, the stability results for the 95% confidence intervals either remain unstable or are in what we have called the ±.5 to ±1 unstable region of the stable interval.

It is undoubtably the case that ad hoc historical explanations can always be brought forth to explain those instances which do not neatly fit predicted patterns. Nevertheless, it is worth noting that if we were to rank order the five crises on the basis of their overall intensity and significance for the parties concerned, it would probably be the case that the 1970 USSR-USA crisis would fall at the bottom of the ordering. Unlike the 1973 USSR-USA crisis, there was no world wide alert; and unlike any of the other three crises, there was no overt violence involving the two participants. While both the USA and USSR were very concerned about what was taking place in Jordan, neither ultimately intervened in an overt military way. Consequently, the stable interaction pattern detected for the best fitting model for the USSR-USA in 1970 may, in fact, reasonably reflect the interaction pattern of this particular crisis.

It would appear then that whether we use the overall best fitting model or the model which best fits each individual crisis, the stability analysis suggests that six months prior to most crises, particularly those which might be considered more intense, the pattern of interaction is unstable. However, before we can legitimately trust such a conclusion, a number of additional analyses are required. Specifically, we need to know whether the pattern of interaction between the same nations is stable in periods when there is no crisis. Ideally then we would like to find six month intervals for each of the five pairs of nations during which the interaction pattern was "normal." Doing a completely comparable analysis of finding the best overall fitting model and the best fitting model for each pair of nations, we would want to assess whether during periods of normal interaction the pattern is stable. Unfortunately, however, such an analysis is exceedingly difficult given the WEIS data set. There are simply not an adequate number of events for most pairs of nations for six month periods in which no crisis occurred. There is, however, one possible exception to this: the USSR and USA. We have, therefore, attempted to make a small but very inconclusive comparison of this pair for the non-crisis period between July and December, 1969 with the results obtained for the two crises involving these two nations.

Table 10 reports the average adjusted R^2 for the two nations for each model together with the standard deviation. Each model was run only for two different measurement procedures: CO, or the simple frequency counts, and CS, the scaled values. These are reported separately in rows 1 and 2, and 3 and 4 respectively. It is clear from Table 10 that the best fitting models are Models 8 and 9 both of which are once again the "net hostility" versions of the Richardson model. There are, in

TABLE 10

A COMPARISON OF ADJUSTED R^2 ACROSS MODELS FOR A NON-CRISIS

	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8	M 9
USSR-USA CO: $\bar{x}_r$	.370	.038	.398	.416	.372	.413	.072	.561	.553
σ_r	.098	.031	.010	.064	.038	.023	.038	.060	.050
CS: $\bar{x}_r$	.396	.038	.392	.385	.369	.349	.034	.498	.491
σ_r	.036	.040	.086	.077	.120	.104	.014	.026	.045

addition, two other interesting aspects of the comparison between the two USSR-USA crises and the one USSR-USA non-crisis. For the crisis periods, Model 8 did exceedingly poorly while Model 7 did rather well. Exactly the reverse appears to be the case for the non-crisis period. Thus it would appear that during crises, the change in net hostility emitted by a nation is principally a function of what that nation did previously while during a non-crisis period the change in net hostility is primarily a function of the net hostility emitted by the opponent. The second interesting aspect of the crisis-non-crisis comparison is the fact that Model 9 once again appears to give generally good fits; while not quite as good as Model 8, Model 9's fit is almost as good. Thus it would again seem that if a decision maker had to choose between models, he would be led to a consideration of the net hostility version of the basic Richardson model as his overall best model.

We turn finally then to the stability analysis of the non-crisis period. These results are reported in Table 11. Unfortunately, the results are not as clear cut as one might wish. While it is true that the interaction is stable for this period when using the actual estimates, we obtained a similar result for the crisis periods. Hence, it is necessary to compare the 95% confidence interval results for the non-crisis period with those obtained for the crisis periods. As can be seen in the last column of Table 11, these findings are ambiguous. While by the +1 to -1 criterion this period would be considered stable, since it was argued earlier that eigenvalues above .5 and less than -.5 indicated an unstable area within the stable region, it would appear that this non-crisis period, when examined using either Model 8 or 9, also produces an interaction pattern that is approaching instability.

TABLE 11

STABILITY ANALYSIS FOR A NON-CRISIS PERIOD

	ORIGINAL ESTIMATES		STABLE or UNSTABLE	95% CONFIDENCE INTERVAL ESTIMATES				STABLE or UNSTABLE
	λ_1	λ_2		λ_1	λ_2	λ_1	λ_2	
USSR-USA								
M 8	.1115	.1075	S	-.2931	-.3126	.5220	.5218	?
M 9	.1528	.0972	S	-.1273	-.5043	.7071	.4245	?

However, we can look at the stability analysis of Table 11 in a somewhat different light. Suppose we compare the degree of instability for the non-crisis period with the degree of instability found for the USSR-USA during a crisis. By "degree of instability" we mean the absolute value of the largest eigenvalue. We can make this comparison between the best fitting models and between the stability results for the crisis and non-crisis for the overall best fitting model, Model 9. It would seem that such a comparison would make most sense if confined to the USSR-USA 1973 crisis, since the results for this model are less ambiguous and, as discussed above, this was clearly the more intense of the two crises. The comparison is shown in Table 12. It is obvious from this contrast that there is a difference between the degree of instability in a crisis and non-crisis period. Indeed, this comparison shows that if the best fitting models are used, the crisis period is highly unstable while the non-crisis period almost falls in the "safely stable" region, i.e., between ±.5.

Obviously these results are exceedingly tentative and in no way conclusive. They do, however, suggest that the search for a best fitting model and the use of stability analysis may provide an important key that could differentiate between crisis and non-crisis patterns of interaction. But while these results are intriguing, it is clear that considerably more comparisons and analyses must be done before we can draw any worthwhile conclusions.

TABLE 12

COMPARING DEGREES OF INSTABILITY BETWEEN CRISIS AND NON-CRISIS

	LARGEST EIGENVALUE (ABSOLUTE VALUE)	
	CRISIS (USSR-USA-1973)	NON-CRISIS
M 9 CO	1.190	.707
Best Fitting Model Crisis: M 5 CO Non-Crisis: M 8 CO	2.280	.522

REFERENCES

Andriole, Stephen J. and Robert A. Young. "Toward the Development of an Integrated Crisis Warning System," International Studies Quarterly, Vol. 21 No. 1, (March 1977), pg. 107-150.

Krasovskii, N. N. Stability of Motion, (Stanford, CA: Stanford University Press, 1963), p. 83.

Richardson, Lewis F. Arms and Insecurity, (Pittsburgh: Boxwood Press, 1960).

Zubov, V. I. Methods of A. M. Liapunov and Their Application, (Groningen, The Netherlands: P. Noordhott Ltd., 1964), p. 160.

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